Realizing the Smartness in Robot-Assisted Risky Intervention, Search, Rescue and Environmental Surveillance: a Feasibility Study on Firefighting

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This proposal is submitted to the European Commission
Marie Skłodowska-Curie actions

Introduction

Where are the robots?

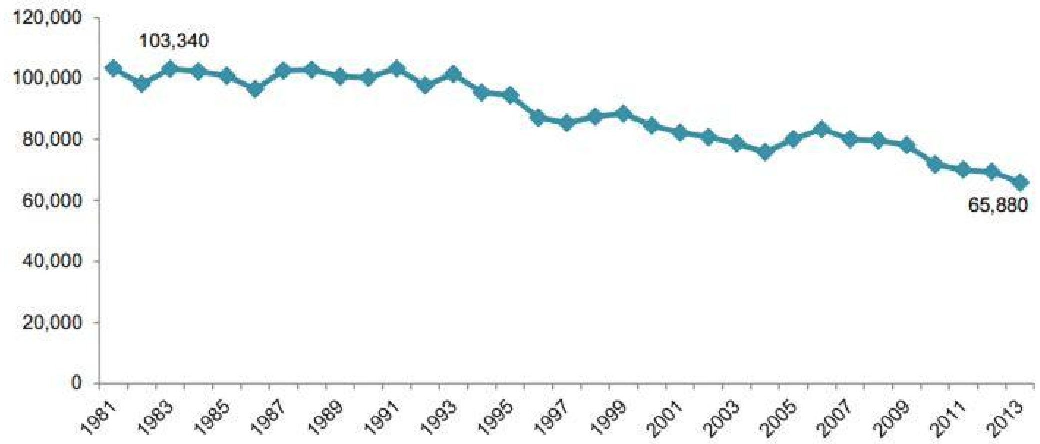
Kumamoto Earthquake

(Source: YouTube Japan Earthquake 2016 video

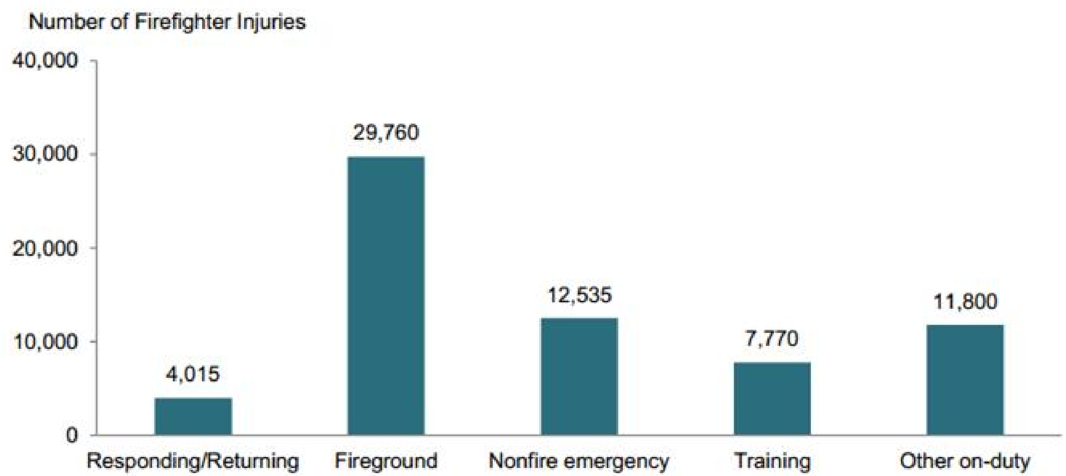
Introduction

On-the-Spot Operational Condition
(Source: https://www.guardians-project.eu/)

Introduction



Firefighter Injuries by Year, 1981-2013[1]



Firefighter Injuries by Type of Duty, 2013[1]

[1]*NFPA's report, U.S. Firefighter Injuries - 2013*

Introduction

Following the wall/hose

(Source: IEEE Spectrum 2013)

Following the lifelines with knots

(Source: http://www.offset.com/photos/95545)

Current Low-Tech Practices in Location & Navigation

Introduction

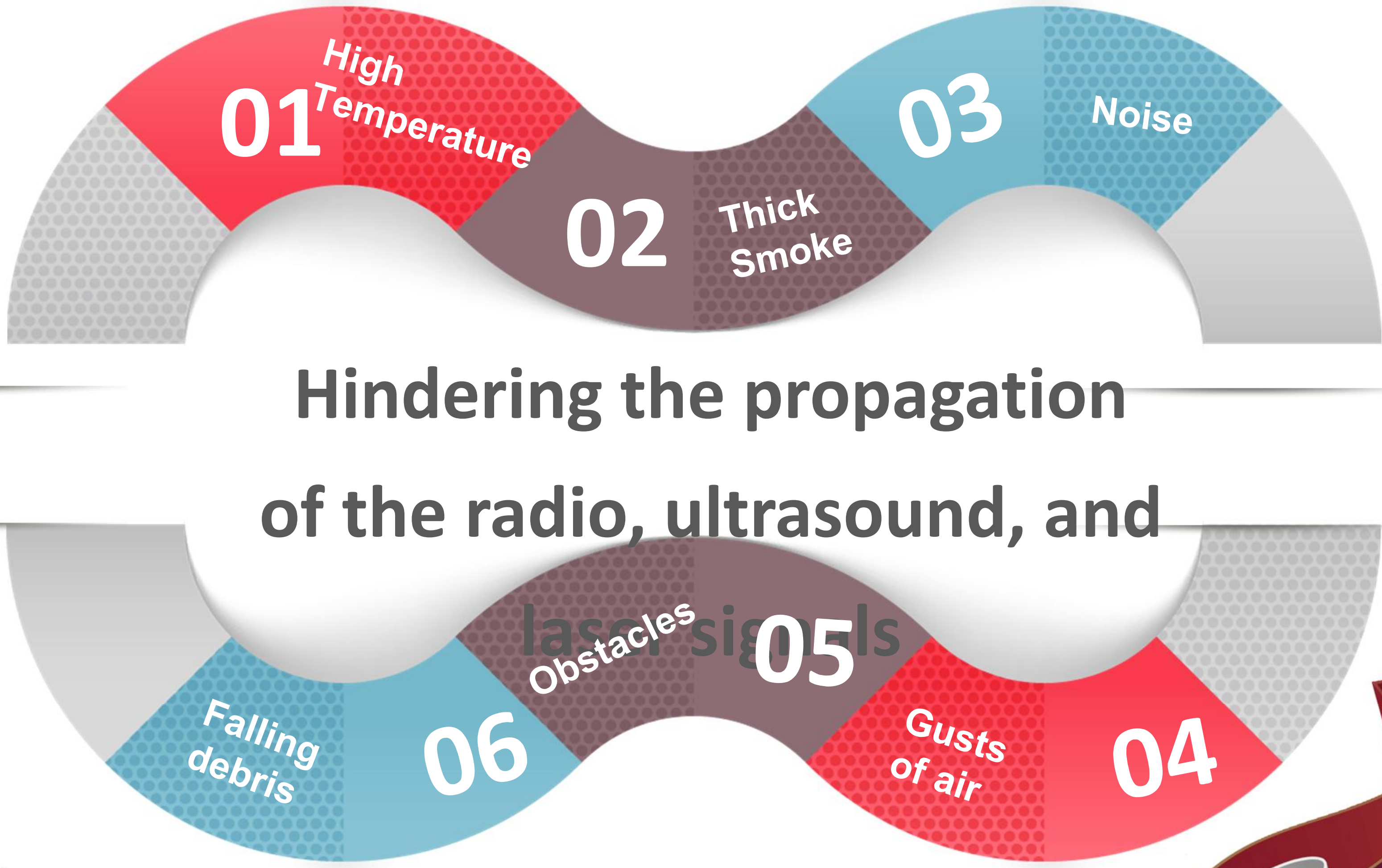
Equiped with PASS (Personal Alert Safety System)

(Source: Kerrian's notebook, 2014)

Current Low-Tech Practices in Location & Navigation

Introduction

Why High-tech devices are generally inefficient and even failed?



Hindering the propagation of the radio, ultrasound, and laser signals

Introduction

Why High-tech systems are generally inefficient and even failed?

- Crawl/walk in unusual patterns → Body-worn sensors end up at odd angles

- Operate device in darkness with gloves → Insufficient information send out.

- High requirements for the devices (robustness to withstand rough handling, high temperatures)

Introduction

Today's Information-Poor Fire Ground

- **Real-time data extremely limited**
- Few sensors
- Limited communication links
- **Small teams take action based on local observables**
- Firefighters observe, analyse, and take actions
- **Some teams interact with ICs over radio**
- Not all teams in real-time communication
- **ICs direct action based on limited available information**
- ICs use info and knowledge to build a mental model
- ICs use mental model to issue commands to the teams
- ICs may not know the outcome of individual commands
- ICs may not know success or failure until end of an event

Introduction

Today's Information-Poor Fire Ground

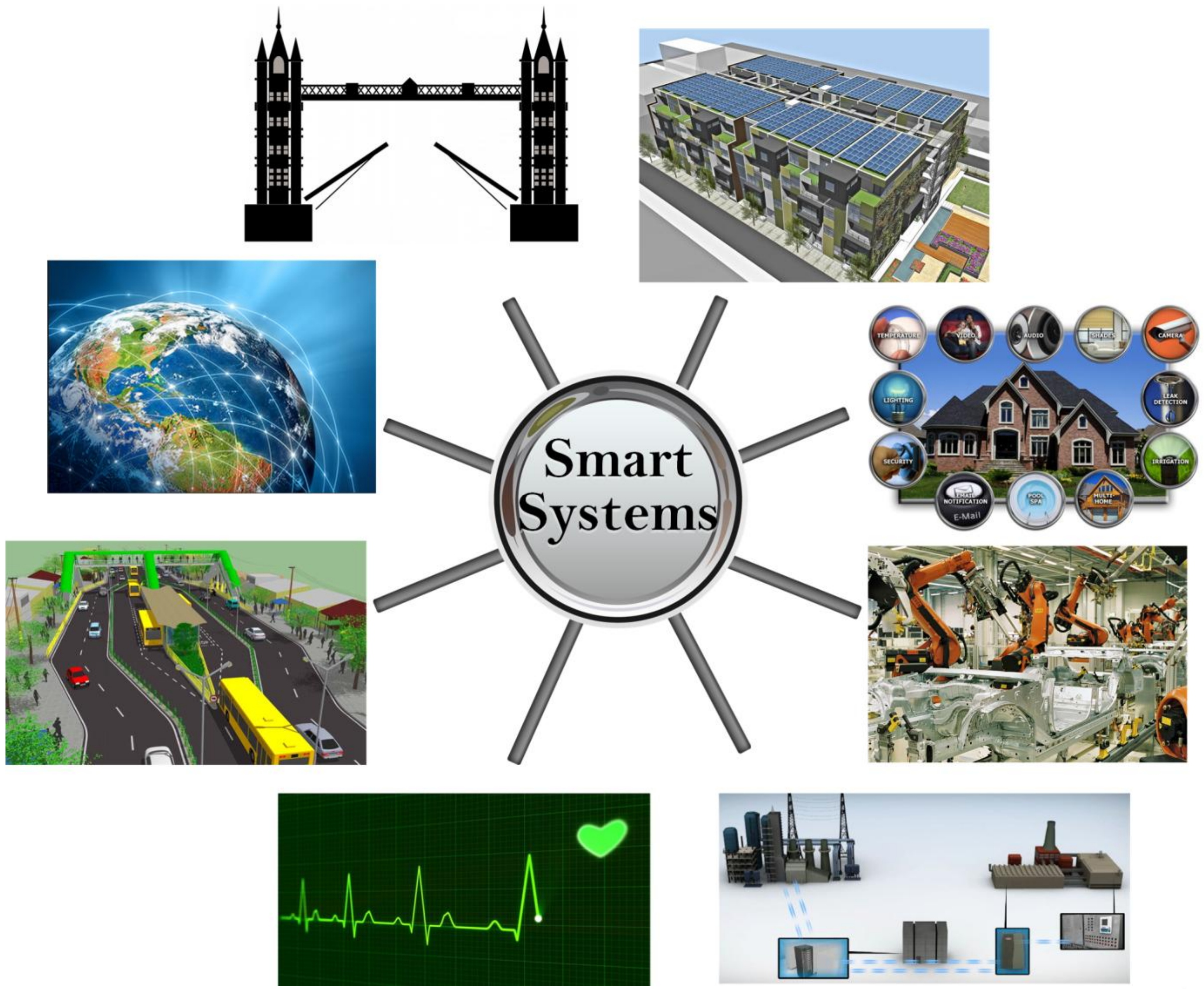
The reachability of **real-time information** on the conditions on the fire ground is a crucial factor in the guidance of rescue actions together with feasible counter-plans. Unfortunately the firefighting environments are normally hard to reach and restricted in accessibility by **obstacles**, **tumbledown architectures** and **visibility** by smoke, dangerous gasses or dust. Lacking of information on location of fire, firefighters and victims, and the search and rescue opportunities are **previously unimaginable** due to lack of situational conditions and real-time information for targeted **decision making**.

Introduction

Cruxes for Firefighting Operations

Introduction

Today's Smart systems



Introduction

What is Smartness?

The idea of “smart” should include not only system **autonomy**, but also system **resiliency** to a wide variety of possible internal disturbances as well as external dynamics. In this regard, it is plausible that smart be characterized by the **cognitive and physical interactions** and **integration** of humans, machines, and organizations to control the system’s performance and manage its resilience.

Introduction

Why smartness is needed in firefighting operation?

- Fire losses/costs still too high
- Smartness offers opportunities previously unimaginable

- Lack of **information** on location of firefighters, victims & fire
- Lack of **data** on thermal conditions, gas-phase
- Global data collection, central analytics, targeted **decision making support**
- **Real-time 3D and dynamic** information, where & when is needed

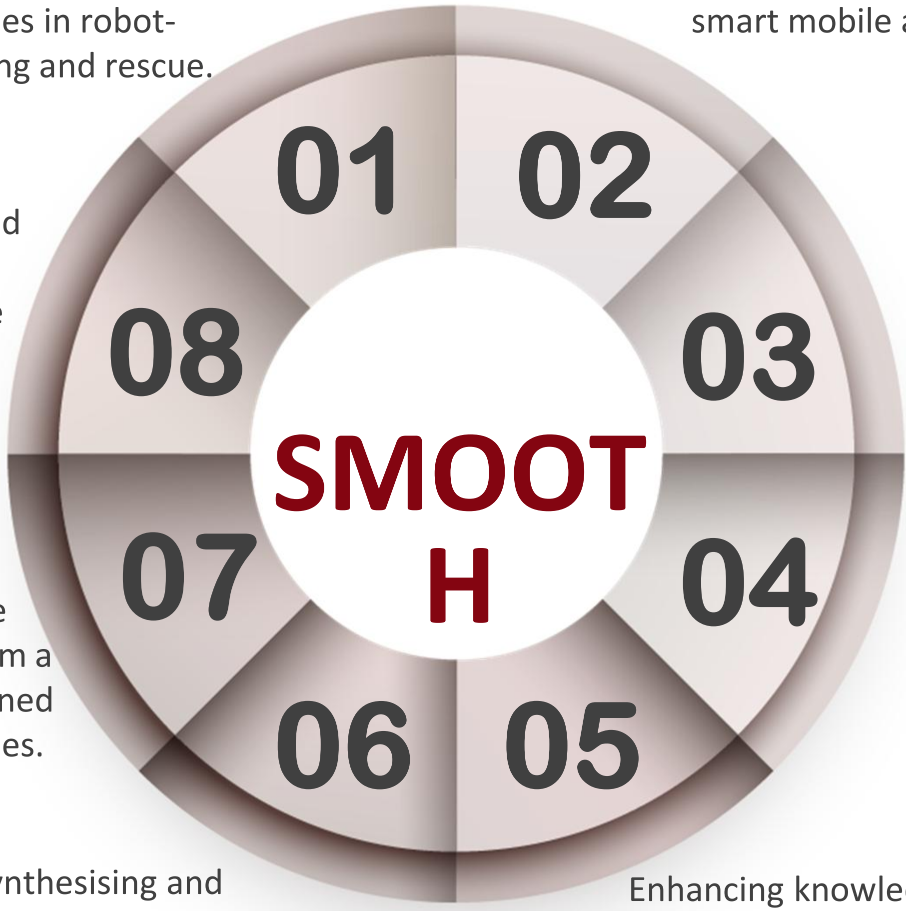
- Smartness enables efficient utilization and assistance of robotic platforms (**H2R and M2M interactions**)

Objectives

Identification of the disaster challenges, requirements, and management issues in robot-assisted firefighting and rescue.

Design and establishment of remote control, H2R interaction interfaces and smart mobile ad hoc networks

Design and test a virtual intelligent platform prototype with DSS and intelligent interface for 3D timely dynamic sensing and perception.



Innovating and implementing a smart robotic platform

Enhancing knowledge and capacity of firefighters and ICs working in firefighting operations

Synthesising and benchmarking the attributes of a promising robot-assisted smart firefighting system

Providing a platform to reinforce and promote the existing collaborations from a viewpoint of multi-disciplined researches and technologies.

Conducting validation and testing and providing results for evaluating the developed system

State-of-Art

Firefighting Robotic Platforms

Robot	Type	Operating Region	Capabilities	Operating Mode	Perception	Portability	HPT	Country of Origin
Anna Konda	Snake-like robot	Indoor/ Outdoor	Fire extinguishment/ Visual perception	Obstacle-aided/ Autonomous	Thermometer/ Visual camera	Medium	Poor	Norway
LUF60	UGV	Outdoor	Fire extinguishment/ Smoke dispelling/ Stair climbing	Remote control/ Rubber track system	Visual camera	Poor	Poor	Germany
SARRIR	Humanoid robot	Indoor	Omnidirectional walking/ Manipulating fire suppressors	Parallel actuated/ Autonomous	Thermal IR stereo/ Visual camera	Poor	Medium	United States
Parosha Cheatah GOSAFER	UGV	Outdoor	Fire extinguishment/ Cutting Extinguisher/	Remote control/ Rubber track system	Thermal image camera/ Laser range finder/ Acoustic detection	Poor	Medium	Sweden
TAF 20	UGV	Outdoor	Fire extinguishment/ Smoke dispelling/ Obstacles sweeping	Remote control/ Rubber track system	N.A.	Poor	High	Germany
FIREMOTE	UGV	Outdoor	Fire extinguishment/ Visual perception	Remote control/ Rubber track system	Visual camera	Poor	Poor	United Kingdom
Brokk	Excavator-like robot	Indoor/ Outdoor	Demolition/ Stair climbing	Remote control/ Hybrid locomotion	N.A.	Medium	High	Sweden
FRIGO-M	Mobile robot	Indoor	Information collection	Remote control	Visual camera	Medium	Poor	Japan
Jet Fighter	UGV	Outdoor	Fire extinguishment	Remote control	Visual camera	Poor	Poor	Japan
SACI 2.0	UGV	Outdoor	Fire extinguishment	Remote control	Visual camera	Poor	Poor	Brazil
Archibot	UGV	Indoor	Fire extinguishment/ Stair climbing	Remote control	Visual camera	Medium	Poor	South Korea
DOK-ING JELKA	UGV	Outdoor	Fire extinguishment	Remote control	N.A.	Poor	Medium	Croatia
Hoya	Spherical robot	Indoor	Information collection/ Reconnaissance	Autonomous	Thermometer/ Visual camera	High	Poor	South Korea
AFFMP	Mobile robot	Indoor	Fire extinguishment/ Monitoring	Autonomous	Flame/ LDR	Medium	Poor	Malaysia
QinetiQ	Mobile robot	Indoor	Fire extinguishment	Remote control	Visual camera	Medium	Poor	United Kingdom
WL-6000	UGV	Outdoor	Fire extinguishment/ Smoke dispelling/	Remote control/ Rubber track system	Visual camera	Poor	High	China
Rainbow 5	UGV	Outdoor	Fire extinguishment	Remote control	Visual camera	Poor	Poor	Japan
OLE	Robot bug	Indoor/ Outdoor	Fire extinguishment	Autonomous	Thermometer	Medium	Poor	Germany

* UGV- Unmanned Ground Vehicle, HPT-Heavy Physical Tasks.

Comparison of Firefighting Robots based on Key Features

State-of-Art

Location & Navigation Support Sensors

- **UV detectors** and **UV light emitting diodes** (early stage fire detection), not able to determine the position.
- **Smoke detectors**
- Light detection and ranging (**LIDAR**)(attenuated with smoke visibility).
- **Visual camera** for video surveillance (not applicable to fire smoke environments).
- **Sonar/Ultrasonic sensor** (Not able to accurately measure the distance through fire smoke).
- RGB-depth sensor (**Kinect™**) (Fails to provide 3-D imaging of the scene).
- **Thermal infrared (IR) camera (TIC)** perform well with long wavelength IR range.
- Frequency modulated-continuous wave (**FMCW**) radar (not real-time, needs over 20s to scan the space and build the 3-D map)

State-of-Art

Location & Navigation Support Systems

One cause of failure is coverage, which can be limited by a particular signal's range or the number of devices deployed .

	Function							
Name	Track-ing	Navi-gation	Tech-nology	Deploy-ment	Floor plan	Components	Limitations	Added features
Prototypes								
PPL	Yes	No	RF ranging, inertial sensors	Strategic	Optional	Multiple receivers outside, mobile transmitter	Performs poorly in metal structure or large buildings	No
SmokeNet	Yes	No	RF finger-prints	Pre-installed	Required	One beacon per room, wearable receiver	Sensitive to changes in the environment	Environment monitoring, communi-cation
LifeNet	Dis-tance	Yes	Relative ultrasound direction	Implicit	No	Beacons every few meters, wearable sensor	Beacons can be moved or destroyed	Environment monitoring, communi-cation
PDR alone	No	Yes	Inertial sensors	No	Optional	Shoe-mounted sensor	Drift, unpredictable error	No
Map matching with particle filter	Yes	No	Inertial sensors	No	Required	Shoe-mounted sensor	PDR drift	No
Map matching with RFID	Yes	No	Inertial sensors, RFID	Strategic	Required	Multiple inertial sensors	PDR drift	Posture monitoring
Flipside RFID	Yes	No	Inertial sensors, RFID	Pre-installed	Required	Shoe-mounted sensor, wearable RFID reader, RFID tags	PDR drift	No
Relate Trails	No	Yes	Inertial sensors, relative ultrasound direction	Implicit	No	Shoe-mounted sensor, beacons, wearable sensor	Beacons can be moved, PDR drift	Environment monitoring, communi-cation
HeadSLAM	Yes	Yes	Inertial sensors, laser range scanner	No	No	Head-mounted inertial sensors and scanner	Scanner fails in low visibility, PDR drift	Environment monitoring, communi-cation

Comparison of Location Support Systems based on Key Features

State-of-Art

Decision Support & Recommendation System

- Current practices are mostly **Experience-based** (for initial reasonable decision).
- Recognition-Primed Decisions (**RPD**). (**experience-oriented**. Mental simulation, mapping to familiar prototype and make decisions)
- From the viewpoint of **disaster (fire) management** for policy/strategy making.
- Lacking of providing **decision support to ICs**.
- Lacking of **real-time data-driven** approaches.
- **Consolidating** locally and globally consistent fire data across **different time and spatial scales**.
- **Intelligent scheduling and resource allocation** in quick changing dynamic environment and emergent events.
- **Data** must be compiled, processed, and communicated in such a way that they are **accessible, understandable, and actionable** at various operating levels (e.g., firefighter, chief, ICs, dispatchers) and phases (e.g., before the fire, on the fire ground, after the fire)

Challenges

Firefighting Robotic Platforms

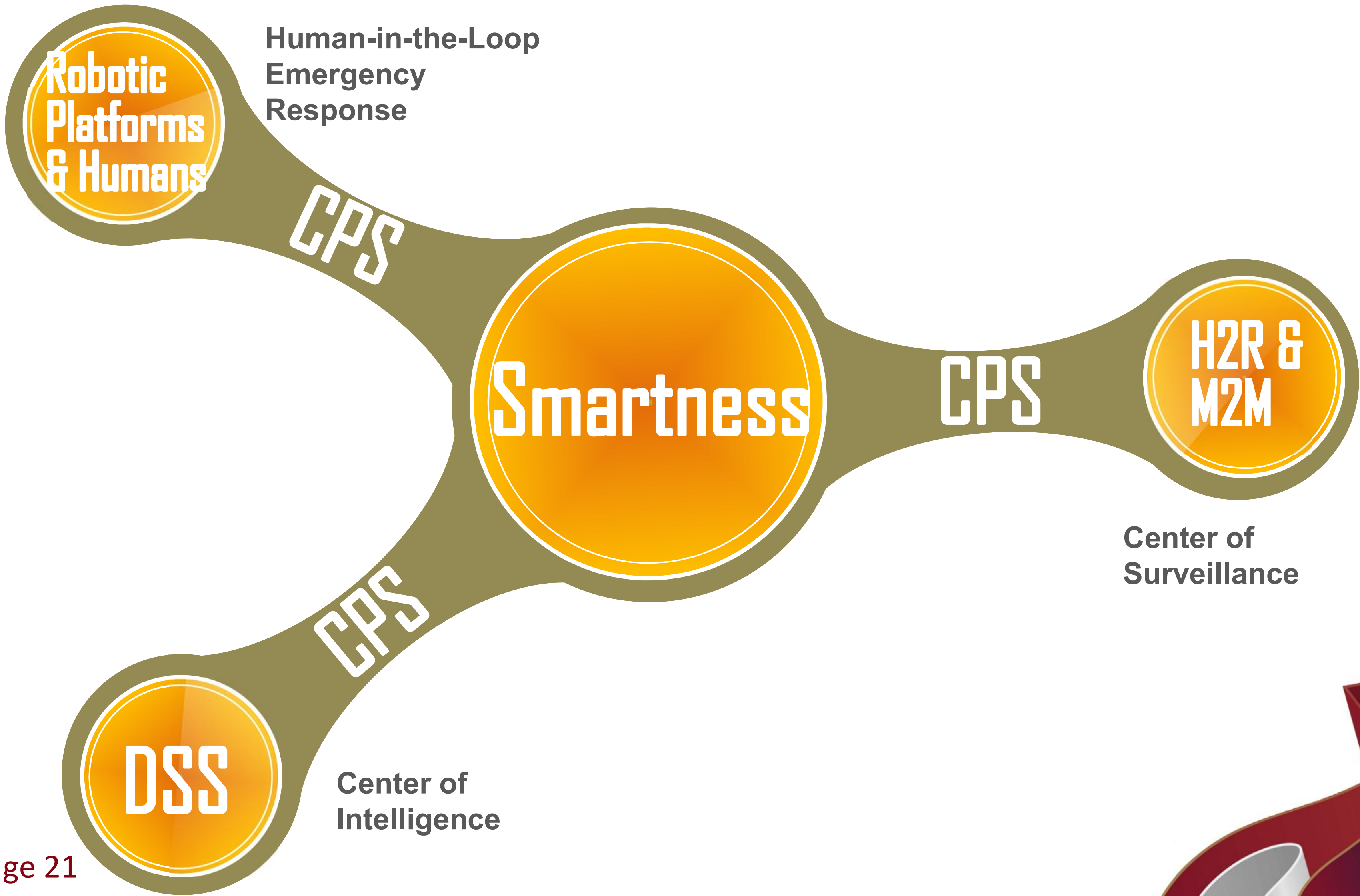
- High degree of **traversability** and be able to reach and operate in inaccessible and hostile areas.
- **Resistance** to heat and heat radiation**.**
- **Supervised and semi-supervised autonomy** with effective human-robot teamwork.
- **Portability** for rapid emergency response.
- Capability of **3D perception and sensing** in restricted visibility and limited RF communication channels.
- Capable of heavy physical tasks (**Obstacle avoidance and sweeping**).
- Flame detection and Fire Extinguishing.
- Situation awareness and intuitive control (**M2M communication**).
- Capable of **dexterous manipulation and maneuveration**.

Challenges

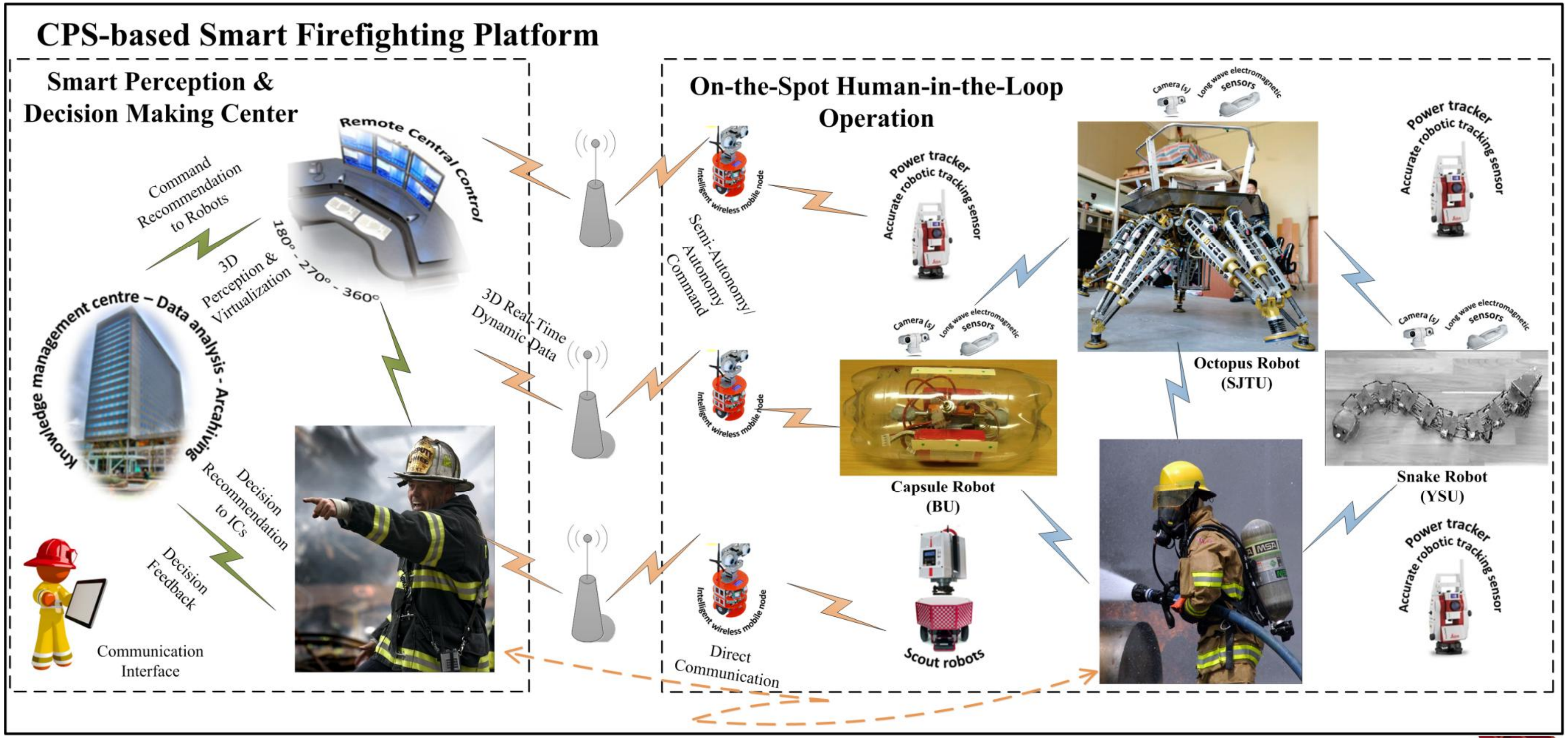
Location & Navigation Support Systems

- Much of the electronic equipment that firefighters use is relatively **low-tech**. High-tech systems tend to be more **fragile** and more **complex**, and **require training.**
- Integrating sensor data with software analytics tools within and across **architectural levels** requires two things: **standardized networking protocols** to cover the wireless communications and **standardized syntax and semantics** to cover the conceptual content. In firefighting, expert understanding of fire protection engineering, fire science, physics, and information science will be needed. To date, **the use of information modelling** in those disciplines has been **virtually non-existent**. The effectiveness of communication on the fire ground is often problematic with the quality and quantity of information highly variable and unreliable.

Framework


Robotic Platforms & Humans
Human-in-the-Loop
Emergency
Response
CPS
Smartness
CPS
H2R &
M2M
Center of
Surveillance
CPS
DSS
Center of
Intelligence

Framework



CPS-based Smart firefighting platform

Conclusion and Future Works

- **Smart Emergency Responses** are novel and promising research areas**.**
- We presented
- Issues on robot-assisted firefighting (motivations, objectives, state-of-art and challenges)
- System architecture to realize smartness (CPS-based) in robot-assisted firefighting
- Future work to provide conceptual design of H2R and M2M interactions and DSS paradigms
- Interface prototyping and validation with participation of end-users

References

[1] P. Liu, H. Yu, S. Cang and Luige Vladareanu, "Robots-assisted smart firefighting and interdisciplinary perspectives," *the 2016 IEEE International Conference on Automation and Computing*, 2016, pp. 395-401.

[2] P. Liu, H. Yu, and S. Cang, "On periodically pendulum-driven systems for underactuated locomotion: A viscoelastic jointed model," *the 2015 IEEE International Conference on Automation and Computing*, 2015, pp. 1-6.

[3] P. Liu, H. Yu, and S. Cang, "Geometric techniques for trajectory planning and chaos control of a bio-inspired autogenetic capsule robot," *the 7th BU Annual Postgraduate Conference*, Bournemouth, 2015.

[4] P. Liu, H. Yu, and S. Cang, "Modelling and control of an elastically joint-actuated cart-pole underactuated system," *the 2014 IEEE International Conference on Automation and Computing*, 2014, pp. 26–31.

Thank You

Questions & Comments?